

The Effect of Prehydrogenation on the  
Hydroconversion of Maya Residuum,  
Part I: Process Characterization

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**EFFECT OF PREHYDROGENATION ON  
HYDROCONVERSION OF MAYA RESIDUUM, PART I:  
PROCESS CHARACTERIZATION**

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**ABSTRACT**

Maya 650 °F residuum was mildly prehydrogenated over a standard, commercially available, hydrodesulfurization catalyst. The product was then distilled to yield hydrogenated Maya 650 °F residuum. This prehydrogenated residuum, and the untreated Maya 650 °F residuum were separately hydroprocessed further at different process severities. The resulting products were then examined by elemental analyses to determine the effects of the prehydrogenation step on overall conversion and product quality.

The primary effect of the prehydrogenation step was to increase the overall conversions for sulfur, MCR, nitrogen, and asphaltenes. As a result, the hydroconversion products derived from the prehydrogenation were substantially

better quality than the corresponding direct hydroconversion products. The prehydrogenation step also lowered the severity required for equivalent residuum hydroconversion upgrading.

## INTRODUCTION

Utilization of heavy crude oil has been the subject of much research as of late [Howell et al. (1985), Campagna et al. (1983)]. The status of current and projected, operating technologies has been reviewed recently [Schuetze and Hofmann (1984)]. The difficulty in utilizing heavy crude oil is generally related to the high concentration of poor quality, nondistillable material found in these feeds. The metals, nitrogen, sulfur, coke precursors, and nondistillable organics all must be dealt with to convert these heavy feeds to transportation fuels.

The current focus is to develop heavy oil conversion processes which are tailored to the conversion of the residuum portion. These processes work on two principles -- adding hydrogen or rejecting carbon. Several technologies are addressing the problem. Some are perturbations of existing refining methods, for examples: 1) residual desulfurization treatment [Hohnholt and Fausto (1986)], 2) new catalyst development [Howell et al. (1985), Campagna et al. (1983)], and 3) coking [Bunch et al. (1979)]. Others are actually developing new technology, for examples: 1) thermal pretreatment [Nakata et al. (1984), Dahlberg and Kuehler (1986)], 2) catalytic additives [Reynolds et al. (1985a,b), Yu and Reynolds (1985), Silva et al. (1983)], 3) combination techniques [Nakata et al. (1984), Sudoh et al. (1984)], and 4) extinction recycle [Takeuchi et al. (1983), Sudoh et al. (1984)].

Examining residuum conversion chemistry should assist in developing better process strategies. In our efforts to understand the chemistry and processing of heavy crude oils and residua, we have applied different analytical techniques to feeds and products --  $^1\text{H}$  and  $^{13}\text{C}$  NMR [Beret and Reynolds (1985)], elemental analyses of separated fractions [Reynolds (1985,1987)], size exclusion chromatography coupled with element specific detection [Biggs et al. (1985), Reynolds and Biggs (1985,1986a,b,c,1987)], electron paramagnetic resonance

[Reynolds et al. (1985c), Reynolds (1985)], reversed phase chromatography [Reynolds et al. (1987a), Fish et al. (1987)], and UV-vis spectroscopy [Reynolds et al. (1987b)]. We have also examined different forms of residuum conversion processes -- thermal and fixed-bed catalytic treatment [Beret and Reynolds (1985), Reynolds and Biggs (1985,1986a), Reynolds et al. (1987b)].

Recently, we have examined the effect of multi-step processing, in particular, pretreatment by mild hydrogenation, followed by residuum hydroconversion at different process severities. This paper reports the effects of prehydrogenation on the product distribution during the upgrading of Maya 650 °F+ residuum (Maya AR), and compares these effects to Maya AR processed under the same conditions without the prehydrogenation step. The characterization of the feeds and products by various analytical methods, and hydrogen incorporation during the upgrading will be discussed in subsequent papers.

## EXPERIMENTAL

Maya AR was prepared from the corresponding crude oil by single plate vacuum distillation to yield an atmospheric equivalent cut point of 343 °C [650 °F]. Thermogravimetric analyses (TGA) showed the feed to be 98.9% 343 °C+ [650 °F+] boiling material.

Hydrogenated Maya AR (HMaya AR) was prepared by hydrotreating Maya AR at low severity. This was then subjected to a single plate vacuum distillation to yield an atmospheric equivalent cut point of 343 °C [650 °F]. TGA of this feed showed 97.5% to be 343 °C [650 °F] boiling material. The catalyst used was a commercially available, standard desulfurization catalyst having cobalt and molybdenum on alumina.

All upgrading experiments were performed in high temperature, high pressure continuous flow pilot plants. All conditions were in the range typical for residuum hydroconversion [O'Rear et al. (1982)] where the low severity conditions were on the mild end of process severity, the moderate severity conditions were the standard

conditions, and the high severity conditions were on the edge of thermal stability. The prehydrogenation experiments were conducted at mild standard desulfurization conditions [Bridge et al. (1975)].

Elemental analyses were performed by Chevron Research Analytical Services department. Details of the techniques have been described elsewhere [Reynolds (1985)]. Hot heptane asphaltenes were prepared by the addition of heptane at a 40 to 1 v/v ratio at 60 °C. The insoluble material was collected by filtration, dried on a steam table, then weighed. This procedure is not to be confused with the D 2007 and asphaltene precipitations used for residuum characterization [Reynolds (1985,1987)]. The UV-vis determinations were performed by techniques described elsewhere [Reynolds et al. (1987)]. Micro carbon residue (MCR) test was performed as ASTM D 1175.

## ANALYSIS OF FEEDS

### Inspections

Table I shows selected analyses of the feeds used in the residuum hydroconversion experiments -- Maya AR and HMaya AR. Maya AR is typical of residua derived from heavy crude oils having high concentrations of S, N, O, Ni, V, and coking precursors (MCR). In addition, it has a high percentage of nondistillable material (1000 °F+ [565 °C+]), and a low hydrogen-to-carbon ratio (H/C) which is indicative of high aromaticity. These properties are typical when compared to several other heavy residua [Tissot and Welte (1985), Hausler (1985), Asaoka et al. (1983)]. Two different Maya AR samples were used in the experiments. One sample was used to prepare the HMaya AR; the other was used for the hydroconversion experiments. The properties of these two Maya AR samples were similar but not identical.

Table I also lists the same inspections for HMaya AR. The prehydrogenation of Maya AR resulted in an upgraded product, but not substantially enough to not classify HMaya AR as a heavy residuum. The concentrations of impurities of

HMaya AR listed in Table I are less than those of Maya AR, but they are still high enough to cause upgrading problems -- high N, S, metals, MCR, 1000 °F+, and a relatively low H/C.

TABLE I

Selected Inspections of Maya 650 °F Residuum and HMaya 650 °F Residuum			
Feed	Maya AR <sup>1</sup>	Maya AR <sup>2</sup>	HMaya AR
Gravity, °API	8.6	9.8	12
S, wt %	4.28	4.54	2.77
N, wt %	0.52	0.50	0.44
O, wt %	0.31	0.31	0.20
Ni, ppm	78	71	63
V, ppm	409	368	221
H/C	1.47	1.47	1.57
1000 °F+, wt %	54.0	56.0	53.0
MCR, wt %	17.3	16.4	14.7
Asphaltenes, wt % <sup>3</sup>	13.8	14.5	13.7

1. used for hydroconversion experiments.
2. used for preparing HMaya AR.
3. hot heptane insolubles.

### Comparison of Feed Properties

Although the prehydrogenation of Maya AR was very mild, the effects are noticeable in the HMaya AR. Several properties are improved compared to the Maya AR. S and V account for the biggest difference where the HMaya AR values are 40% lower than the corresponding Maya AR values. Both of these changes are expected from desulfurization catalysts [Satterfield (1980)]. Other properties which are not as affected by the prehydrogenation are the N, Ni, 1000 °F+, and MCR, which are 12, 11, 5, 10% lower, respectively, than the corresponding Maya AR values. These changes are also expected from hydrodesulfurization catalysts. A low cracking conversion is due to the upgrading not being done in the thermal reaction regime. The gain in H/C is evidence that hydrogen addition was satisfactorily attained by the experiment. The lower MCR is also an indicator of

this. The hydrogen incorporation was examined by  $^1\text{H}$  and  $^{13}\text{C}$  NMR and the results will be reported in Part II [Beret and Reynolds (1987)].

Summarizing the effect of mild prehydrogenation shows the HMaya AR: 1) is slightly better quality due to the reduction in concentration of most of the impurities (particularly S and V), and 2) should be an easier feed to process by standard catalytic methods (less severity required due to lower S [Bridge et al. (1975)]; longer run life due to less metals [Tamm et al. (1981), Galiasso et al. (1983)].

## PRODUCTS

Both Maya AR and HMaya AR were subjected to further hydroconversion. Maya AR was processed at low, moderate, and high severities. HMaya AR was processed at the identical conditions for comparison. However, operability was poor with the HMaya AR at the high severity condition, so this product was not used in the comparisons.

### Maya 650 °F Residuum

Table II lists the whole liquid product properties for the Maya AR upgrading experiments. Several changes are seen in the products compared to the feed as a function of severity.

Inspection of the properties in Table II show substantial upgrading of Maya AR was achieved at all severities. Virtually all the properties change, with most notably reductions in heteroatom and metals contents. Asphaltene, MCR, and 1000 °F+ contents are also lower, and H/C is higher. Measured hydrogen consumption for all three severities are also listed in Table II. As expected for hydrogenative conditions, the hydrogen consumption increases with increasing process severity. Roughly one-fourth of the hydrogen consumption is due to heteroatom removal. The balance is due to hydrogenation, cracking, and gas formation reactions [Gary and Hardwick (1984)].



TABLE II

Inspections of Whole Liquid Products from the Hydroconversion of Maya AR			
Process Severity	Low	Moderate	High
Gravity, °API	20.2	22.8	24.7
N, wt %	0.32	0.32	0.32
S, wt %	1.10	1.04	1.01
O, wt %	0.20	0.13	0.10
1000 °F+, wt %	25	20	11
H/C	1.61	1.64	1.65
Ni, ppm	32	24	15
V, ppm	111	62	30
Asphaltenes, wt % <sup>1</sup>	7.1	5.1	3.6
MCR, wt %	9.1	8.2	6.1
H <sub>2</sub> Consumed, SCF/Bbl	930	1140	1210

1. hot heptane insolubles.

Table III lists the conversions for the hydroprocessing of Maya AR at various process severities. As seen in the whole liquid product properties listed in Table II, several properties of Maya AR are effected at all severities. For the low severity case, S and V conversion are high, while Ni, cracking (1000 °F+), coking (MCR), and asphaltene conversions are moderate. Only N removal is low.

TABLE III

Conversions* of Maya AR as a Function of Hydroconversion Process Severity, %			
Severity	Low	Moderate	High
1000 °F+	54	63	80
MCR	47	53	65
N	39	39	39
S	74	75	76
Ni	59	69	81
V	73	85	93
Asphaltene	49	63	74

\* Conversion =  $(100(\text{wt \% in feed} - \text{wt \% in product}))/\text{wt \% in feed}$ .

Comparing these conversions as a function of process severity, several trends appear. Figure 1 shows these trends as a function of severity. Demetalation, asphaltene, MCR, and cracking conversions increase with severity, while desulfurization and denitrification remain unaffected. The cracking conversion is commensurate with the increase in temperature needed to increase the process severity. This is also demonstrated in the increase in both Ni and V removal, which have been shown to have thermally induced demetalation pathways in addition to catalytic demetalation pathways [Reynolds and Biggs (1985,1986)]. MCR conversion increases also with severity. This suggests a combined thermal and catalytic pathways yielding the incremental conversion for this property also.

Measured hydrogen consumptions shown in Table II increased with process severity due to increasing light gas production. Cracking reaction rates are known to increase faster with temperature and time than hydrogenation reactions [Gary and Hardwick (1984)]. This is realized with the increase in cracking conversion while desulfurization and denitrification were insensitive to process severity. The hydrogen incorporation during hydroconversion of Maya AR and HMaya AR has been examined by  $^1\text{H}$  and  $^{13}\text{C}$  NMR and will be discussed in Part II [Beret and Reynolds (1987)].

#### Hydrogenated Maya 650 °F Residuum

Table IV lists selected whole liquid product properties from the HMaya AR upgrading experiments. Several changes are seen in the products when comparing to the feed and as a function of severity.

Inspection of the properties in Table IV show substantial upgrading of HMaya AR was achieved at both low and moderate severities. Changes are seen in all the properties listed, with the most dramatic changes occurring in the removal of S. Metals, N, O, asphaltenes, 1000 °F+, and MCR concentrations are lower than in the feed, and H/C is higher. Table IV also lists measured hydrogen consumption for both severities. As seen for Maya AR, the amount of hydrogen consumed increases with increasing severity. Less than 30 % of the hydrogen goes to

heteroatom removal. The balance goes to hydrogenation, cracking and gas formation reactions.

TABLE IV

Inspections of Whole Liquid Products from the Hydroconversion of Hydrogenated Maya AR		
Process Severity	Low	Moderate
Gravity, °API	22.1	23.8
N, wt %	0.24	0.25
S, wt %	0.74	0.66
O, wt %	0.16	0.12
1000 °F+, wt %	29	23
H/C	1.66	1.69
Ni, ppm	29	21
V, ppm	99	57
Asphaltenes, wt % <sup>1</sup>	6.4	4.4
MCR, wt %	8.1	7.2
H <sub>2</sub> Consumption, SCF/Bbl	620	820

1. hot heptane insolubles.

TABLE V

Conversions* of Hydrogenated Maya AR as a Function of Process Severity During Hydroconversion, %		
Severity	Low	Moderate
1000 °F+	45	57
MCR	45	51
N	45	43
S	73	76
Ni	54	67
V	55	74
Asphaltenes	53	68

\* Conversion = (100(wt % in feed - wt % in product))/wt % in feed.

Table V lists the conversions for the upgrading of HMaya AR at the two hydroconversion process severities. As seen in the whole product property distributions in Table IV for HMaya AR, and in Table II for Maya AR, several properties of HMaya AR are affected by the changing of process severity. For the

low severity case, S conversion is high, while metals removal, 1000 °F+, MCR, asphaltene, and N conversions are moderate. For the moderate severity case, all conversions are higher, except for N.

As in the upgrading of Maya AR, several trends appear as a function of process severity. All conversions and removals appear to increase with process severity except for nitrogen and sulfur removal. As before, the cracking conversion increase is commensurate with the increase in temperature needed to attain the process severity. This is also evident in the increase in metals removal which has been shown to have substantial thermal induced demetalation pathways [Reynolds and Biggs (1985,1986a)].

MCR and asphaltene conversions also increase with process severity. The increase in MCR conversion is probably due to hydrogen incorporation, and will be discussed elsewhere [Beret and Reynolds (1987)]. The asphaltene conversion is thought to have a detectable thermal reaction pathway which also has been observed in the behavior of the metal- and S-containing compounds [Reynolds and Biggs (1987a,b)].

#### Effects of Prehydrogenation on Hydroconversion

The product properties and conversions listed in Tables II-V for Maya AR and HMaya AR assist in determining the effects prehydrogenation has on residuum hydroconversion. Examining the low severity products from Maya AR (Table II) and HMaya AR (Table IV) shows at the same conditions, HMaya AR products are better quality than the Maya AR products. For the HMaya AR low severity product, except for 1000 °F+ content, all impurity concentrations are lower than the corresponding value for the Maya AR product. The S, N, and O levels are noticeably lower in the HMaya AR low severity product. In addition, the H/C is 0.05 higher.

The conversions for both Maya AR (Table III) and HMaya AR (Table V) are similar for both low severity cases. The biggest difference is V removal. A significant portion of this is due to the prehydrogenation step removing vanadium

petroporphyrins. UV-vis examination of chromatographic purified porphyrin fractions [Reynolds et al. (1987b)] of Maya AR and the prehydrogenated product are shown as second derivative spectra in Figure 2. The maximum at 572 nm and 534 nm in the top trace are assigned as V petroporphyrins. Using vanadyl Etio porphyrin as the reference, 13% of the V was bound as petroporphyrin. The bottom spectrum is the second derivative spectrum for the prehydrogenation product from Maya AR. The absence of the 572 nm maximum or any other maxima indicates all the metallo-petroporphyrin or related structures have been removed. The V petroporphyrins account for 53 ppm or approximately 1/4 of the additional V removal found in the Maya AR low severity case.

The 1000 °F+ conversions in the low severity case substantially higher for the Maya AR compared to HMaya AR. This may be due to molecules in the residuum which are easily cracked are already converted in the pretreatment step.

Examining the moderate severity properties of Maya AR (Table II) and HMaya AR (Table IV) shows similarities seen in the low severity case comparison. Except for 1000 °F+ concentration, all the properties of the HMaya AR whole product are lower than that of the corresponding Maya AR product. Also the HMaya AR product has a slightly better H/C than the Maya AR product. This is not expected when considering the large difference in the H/C of the two feeds. Closer inspection of the hydrogen incorporation will be discussed in more detail in Part II [Beret and Reynolds (1987)].

Comparing the conversions for the two feeds at the moderate severity condition shows the 1000 °F+ and demetalation conversions are slightly higher for Maya AR. As in the case of the low severity experiments, this is probably due to removal of petroporphyrins and easily cracked molecules during the pretreatment step.

## PREHYDROGENATION AS A PROCESS

To assess the true process implications of the prehydrogenation step, all steps of the process must be added, and then compared to the direct hydroconversion of Maya AR. The prehydrogenation, although very mild, produced some 343 °C-

[650 °F-] boiling material. This was distilled from Maya AR (to make HMaya AR) and must be added back into the final product. This mild process also consumed hydrogen (510 SCF/Bbl) which must be accounted for in the overall yield calculations.

Figures 3 and 4 diagram the overall conversion processes for the hydroconversion at mild and moderate severities of Maya AR with and without the prehydrogenation step. Included in the diagrams are elemental analyses of all the products at various stages of the process. With respect to the feed, N, S, O, 1000 °F+, and MCR are given as wt %; Ni, and V as ppm; gravity as ° API, and H/C as atomic. Included for the whole products are the overall hydrogen consumptions. The wt % distribution are indicated above the lines after each step.

#### Mild Severity Processing.

Figure 3 shows the overall product properties from the mild severity hydroconversion of Maya AR. The top flow diagram shows the process including the prehydrogenation step. Comparing the overall whole product to the hydroconversion product, some differences are seen. Blending of the 650 °F- into the hydroconversion product affords the following changes: 1) increases in the N and S levels (due to the higher concentration of these elements in the overhead), 2) decreases in the 1000 °F+, MCR, and metals (due to the lack of these materials in the overhead), and 3) increases in the H/C and API gravity.

The bottom flow diagram of Figure 3 shows the product properties from the mild severity hydroconversion of Maya AR not using the prehydrogenation step. Comparing the whole product values from this figure to those whole product values from top flow diagram, overall yields and product qualities are better in the prehydrogenation case.

The most dramatic difference in the two products is the S, N, and MCR levels. This is primarily due to the added prehydrogenation step which accounts for most of this additional conversion (see Table I). However, the

prehydrogenation step does also make the S and N removal easier, because there is some additional conversion seen in the hydroconversion step when compared to the process without prehydrogenation (see Tables III and V).

For V removal, the prehydrogenation step was most effective (see Table I). However, instead of making the removal easier in the hydroconversion step, this decreased the conversion (see Tables III and V). The origin of this phenomenon is not clear, but does suggest in processing there are, from a simplistic view, at least two types of V compounds, easy and hard to remove.

Figure 3 also shows the overall hydrogen consumptions. The prehydrogenation step only increases the overall hydrogen consumption by 10%. This is encouraging process performance when considering all the additional upgrading the prehydrogenation step affords. Approximately one third of this incremental consumption can be attributed to the additional heteroatom removal. The balance must go to the cracking and hydrogenation reactions. The prehydrogenation step also leads to lower overall C<sub>4</sub><sup>-</sup> gas formation (2.2% vs 3.7%).

#### Moderate Severity Processing.

Figure 4 shows the overall product properties from the moderate severity hydroconversion of Maya AR. The top flow diagram shows the process with the prehydrogenation step. Blending of the 650 °F- into the hydroconversion product affords the same changes in the whole product as it does in the low severity case: 1) increases the N and S concentrations, 2) decreases the 1000 °F+, MCR, and metals levels, and 3) increases the API gravity. The H/C in this case, however, is not affected.

The bottom flow diagram in Figure 4 shows the whole product properties for the moderate severity hydroconversion of Maya AR not using the prehydrogenation step. Both the liquid yield and the liquid product API are lower than the prehydrogenation case.

As in the mild severity case, the most dramatic difference in the two products is the S and N levels. This additional conversion can almost all be accounted for by the added prehydrogenation step. Essentially, no differences in conversion are observed in the hydroconversion step. Apparently for the moderate severity processing, the prehydrogenation did not make the S and N easier to process in the hydroconversion step, as it did in the low severity case (see Tables III and V). This is also somewhat true for Ni, where the differences in the concentrations in the whole products can be completely accounted for by the prehydrogenation step.

For the the MCR conversions, about one half of the differences between the two products can be accounted for by the prehydrogenation step. The balance is due to effects of the hydroconversion process step. This is expected, because the moderate severity processing required conditions which would invoke some thermal reaction pathways, which both cracking and coking are dependent on.

As in the low severity case, the V removal was decreased probably due to the removal of petroporphyrins in the prehydrogenation step.

Figure 4 also shows the overall hydrogen consumptions. For the moderate severity case, the prehydrogenation step only increases the overall hydrogen consumption 10 %. As in the low severity case, this is encouraging process performance when considering the additional upgrading the prehydrogenation step affords. However, in the moderate severity case, only 20 % of the incremental hydrogen goes to the additional heteroatom removal. The rest goes to cracking and hydrogenation reactions. Gas formation is also substantially higher without the prehydrogenation step. This is expected also because of the required temperatures needed to achieve this process condition invoke some thermal cracking reactions. The fate of the hydrogen in these processes will be discussed in Part II [Beret and Reynolds (1987)].

Table VI shows the overall conversion for the prehydrogenation sequence shown in Figures 3 and 4 for both the mild and moderate severity upgrading. Comparing these values to the values shown in Table III for Maya AR upgraded under the same conditions, the prehydrogenation sequence for processing shows



superior removal and conversion of deleterious materials in Maya AR. For effectiveness of processing, the prehydrogenation of Maya AR favorably assists overall. These results have been discussed above for the particular case and impurity. However, hydrogenation incorporation reactions are different as will be discussed in Part II [Beret and Reynolds (1987)].

TABLE VI

Comparison of Overall Conversions* for the Upgrading of Maya AR by Residuum Hydroconversion with and without Prehydrogenation				
Prehydrogenation Process Severity	Without Low	With Low	Without Moderate	With Moderate
1000 °F+	54	54	63	63
MCR	47	56	53	60
N	39	50	39	48
S	74	83	75	85
Ni	59	63	69	73
V	73	76	85	86
Asphaltene	49	56	63	70

\* Conversion =  $(100(\text{wt \% in feed} - \text{wt \% in product}))/\text{wt \% in feed}$ .

The prehydrogenation sequence exhibits overall better quality products as seen in the above comparisons. The most notable difference was for the low severity case. In the prehydrogenation sequence, metals, asphaltenes, MCR, and 1000 °F+ contents are all approximately 80% of the direct conversion products. N and S are even less. For the moderate severity case, the product qualities obey the same trends, but the difference in the two processing sequences is less dramatic.

There are, of course, drawbacks to this sequence of processing: 1) increase capital costs for added reactors to accomplish the prehydrogenation, and 2) increased hydrogen consumption. In addition, none of the results above take into account differences in product property distributions which is important in yield calculations and integration of the products into refinery streams.

## CONCLUSIONS

Several conclusions can be made assessing prehydrogenation as a processing option in residuum hydroconversion of Maya AR. Prehydrogenation affords:

1) Facile Hydroconversion. Comparing overall conversions in Table VI for the two processing sequences show prehydrogenation makes processing easier.

2) Better Quality Products. Comparing Figures 3 and 4 show the overall products are of better quality for the prehydrogenation sequence.

3) More Hydrogen Usage. As expected, for the additional hydrogenation step, the overall hydrogen consumption is higher for the prehydrogenation sequence. This does, however, increase the overall H/C of the prehydrogenated products for and increases the amounts of impurities removed from both the low and moderate severity cases. This could reduce the hydrogen consumption in further refining processing which are ultimately necessary for the conversion to transportation fuels.

4) High Severity Process Instability. Operability of the HMaya AR was erratic at high severity, therefore the resulting products analyses were not included here. This could be due to several factors, for example, product instability. If we compare the two processing options at equivalent hydrogen usage, high severity processing of Maya AR would be equivalent to moderate severity processing of HMaya AR.

None of these conclusions include economic considerations such as capital equipment, hydrogen costs, or yield distributions. These factors may ultimately determine the feasibility of prehydrogenation as a process option.

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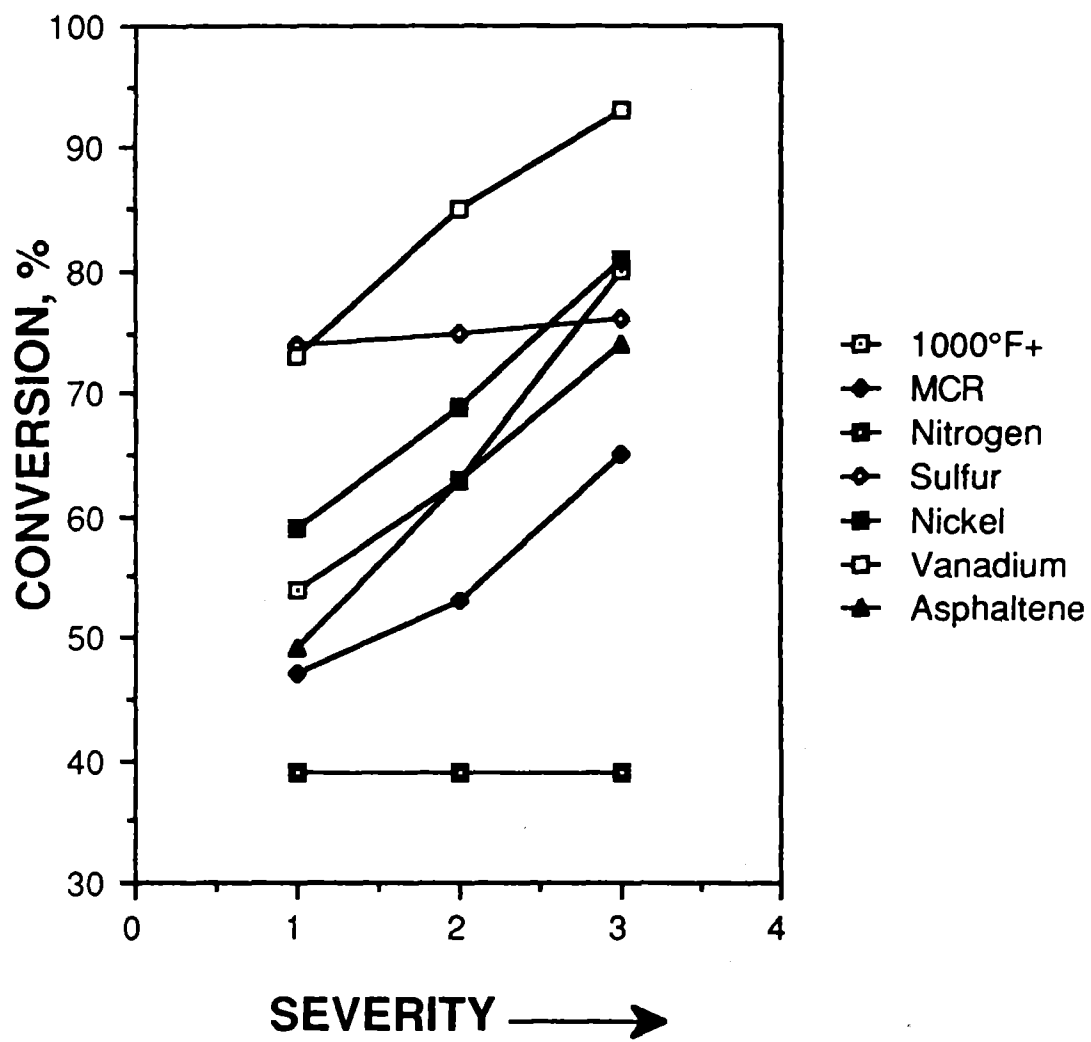
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**Figure 1. Conversions as a Function of Severity for the Hydroconversion of Maya AR without the Prehydrogenation Step.**

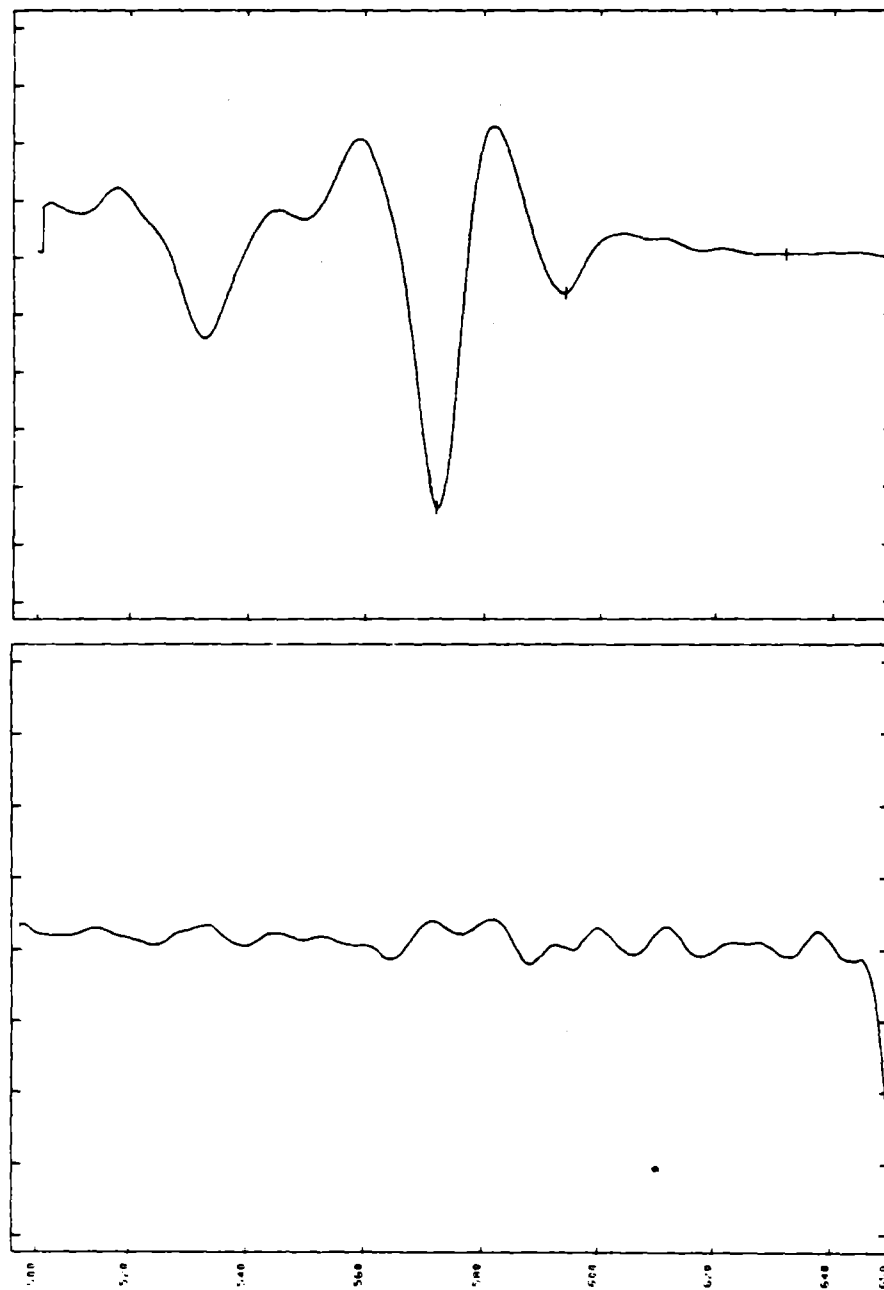
**Figure 2. Second Derivative UV-vis Spectra of Maya AR (top) and the Whole Product from the Mild Prehydrogenation of Maya AR (bottom).**

**Figure 3. Process Flow Diagrams for the Mild Severity Hydroconversion Upgrading of Maya AR with the Prehydrogenation Step (top) and without the Prehydrogenation Step (bottom).**

**Figure 4. Process Flow Diagrams for the Moderate Severity Hydroconversion Upgrading of Maya AR with the Prehydrogenation Step (top) and without the Prehydrogenation Step (bottom).**



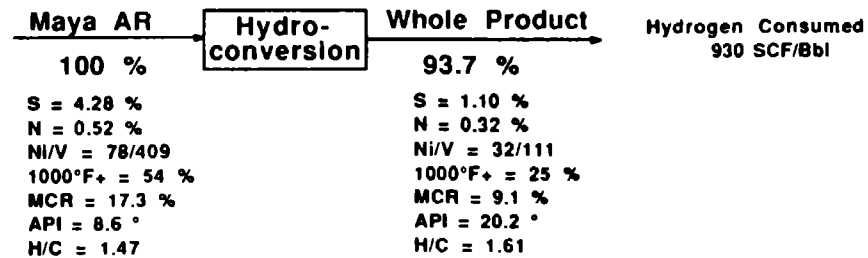
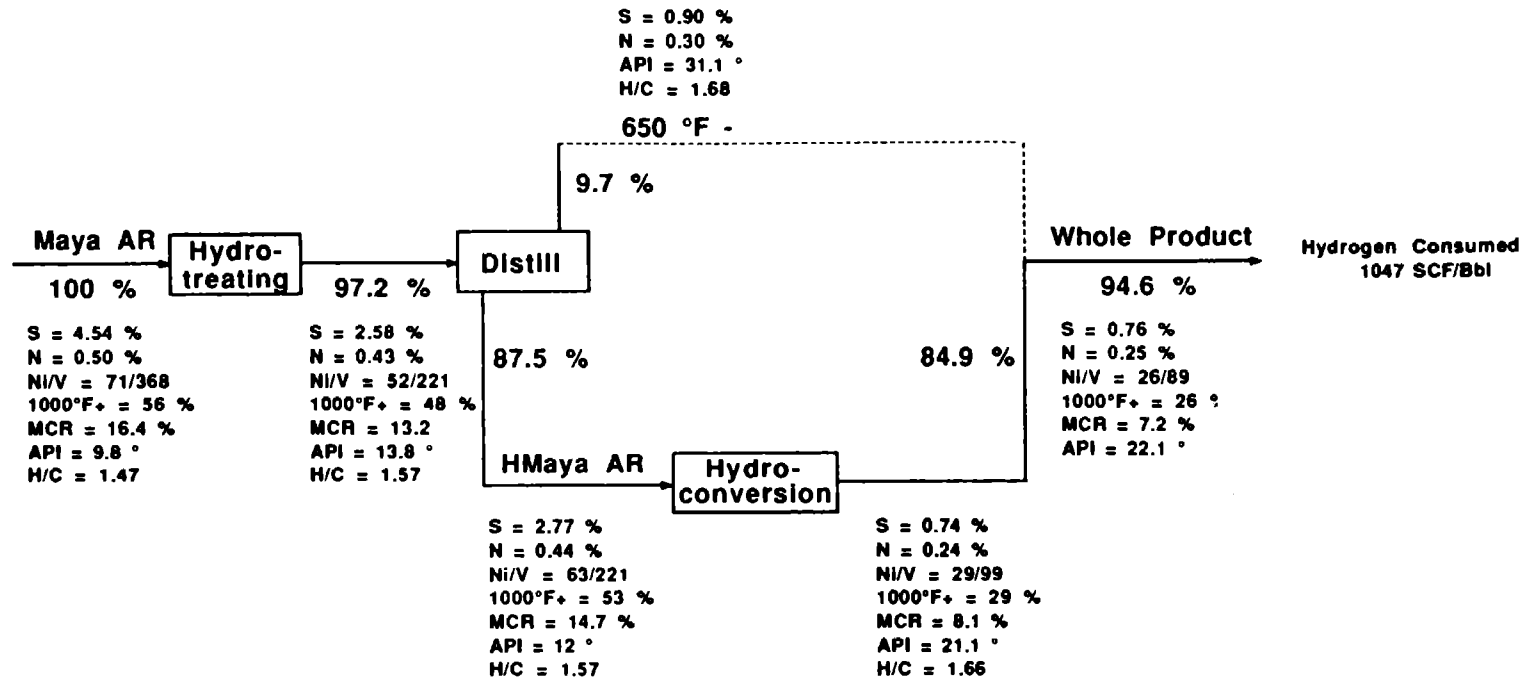
**Absorbance, Second Derivative**



**Wavelength, nm**



# MILD SEVERITY HYDROCONVERSION



# MODERATE SEVERITY HYDROCONVERSION

